Background

The tungsten inert gas (TIG) arc welding process was the first to be combined with a laser beam to produce an arc-augmented laser, or hybrid laser-arc weld in the mid 1970s (1). Since then, laser welding has successfully been augmented with other arc processes such as metal inert/active gas (MIG/MAG) welding and plasma welding. The advantages of using hybrid laser-arc welding for increased productivity include faster welding speeds, improved penetration, enhanced gap bridging capability and reduced porosity compared with conventional laser welding. Hybrid welding has been studied for application in industries such as automotive (5), oil and gas (7, 8), shipbuilding (9) and nuclear (10).

This report reviews the published literature on the capabilities of hybrid laser-arc welding. Also, a programme of experimental work was undertaken to establish suitable procedures for hybrid CO_2 laser-MAG arc welding carbon steel, compared to welding with the individual processes.

Objectives

- To review published literature on hybrid laser-arc welding to establish procedures for initial trials for hybrid CO_2 laser-MAG welding carbon steel.
- To determine process guidelines for using hybrid CO_2 laser-MAG welding technology for welding steel.

Summary of Literature Review

Experimental research into laser-arc hybrid welding has demonstrated that it combines many of the best features of the individual processes. MIG/MAG welding provides a relatively wide bead and good tolerance to variations in fit-up and the possibility of metallurgical control. Laser welding provides deep penetration welds at fast welding speeds. The synergistic action of combining the individual processes is more than simply additive: considerable reductions in costs and improvements in productivity are achievable relative to the separate processes.

The use of filler wire and a more diffuse heat source with the arc process means that hybrid laser-arc welding can tolerate misalignments and large root gaps in thick section welding better than laser welding alone. Therefore the accuracy and tolerances required for workpiece preparation are relaxed.

For the very low additional costs of the arc compared with the laser, hybrid welding reportedly offers faster welding speeds and lower cycle times thus, the production cost per unit can be reduced compared to laser welding. A reduction in investment costs for laser technology will further facilitate the acceptance of the process for future industrial applications. In most cases the enhancement of weld penetration of hybrid welding compared with laser alone welding has been reported. However, this is not always the case. Scott (38) concluded that there were no synergistic effects of the laser increasing the penetration of TIG welds in several aluminium alloys.

However, these results were explained by the low power laser used, which did not produce a keyhole.

Experimental Approach

Following an extensive literature review, a programme of work was undertaken to establish the feasibility of using hybrid CO_2 laser-MAG welding of carbon steel in order to obtain greater weld penetration at faster speeds than for laser welding. Processing parameters investigated in this assessment of hybrid laser-arc welding include gas composition, welding speed, welding direction (laser trailing or leading the arc) and MAG metal transfer mode.

Results and Discussion

The literature review showed that it is possible to improve productivity using the hybrid laser-arc welding process, compared with either laser or MAG arc welding. Costs are considerably reduced using a hybrid laser-arc process compared with a laser only process of equivalent power.

Bead-on-plate welding trials used a MIG/MAG welding torch inclined at 60° to the workpiece, and pulsed and dip metal transfer conditions of equivalent power to the 4kW CO_2 laser. A 3kW MAG arc using a pulsed metal transfer condition, 4kW CO_2 laser, He-Ar-CO_2 shielding gas and the arc trailing the laser was found to give 25% greater penetration than the laser welds. For a given penetration, these conditions also gave a 50% increase in welding speed compared with a laser weld. The thermal efficiency factor of the hybrid process is increased to 0.9, compared with 0.78 or 0.8 for CO_2 laser or MAG welding respectively, for welding speeds up to 3.0 m/min.

Trials were also undertaken to investigate welding with a 4.2kW CO_2 laser augmented with a 12.5kW MAG arc. Spray metal transfer conditions and a shallow torch inclination angle of 40° was used, and the shielding gas was He-Ar-CO_2. The penetration of these hybrid welds was less than the penetration in laser welds. This was due to the high arc currents used in the spray metal transfer condition causing an excess of weld metal in the keyhole, effectively blocking the penetration of the laser.

Main Conclusions

- He-Ar-CO_2 shielding gas was found to give the best combination of process stability and penetration for hybrid 4kW CO_2 laser-3kW pulsed MAG welding.
- The MIG/MAG welding torch trailing the CO_2 laser for a hybrid 4kW CO_2 laser-3kW pulsed MAG welding process was found to increase penetration of the hybrid weld.
- For a constant depth of penetration (in this case 4.2mm penetration) the hybrid CO_2 laser-MAG welding process was capable of increasing welding speed by around 50% compared to laser alone welding.

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- Hybrid CO_2 laser-MAG welding provided an increase in weld penetration of 20-35% compared with laser alone welding at constant welding speed of 3.0 m/min.

- The average process efficiency factor was found to be 0.9 for hybrid 3.8kW CO_2 laser-2.6kW MAG welds, compared with approximately 0.8 for the individual laser and MAG processes. The total weld area of hybrid 3.8kW CO_2 laser-2.6kW MAG welds was greater than the sum of the weld areas for the individual processes below 3.0 m/min.

Recommendations

It is recommended that to improve the penetration and welding speed of bead-on-plate welding carbon steel, the following welding conditions using a hybrid CO_2 laser-MAG welding process are:

- Pulsed MAG metal transfer conditions;
- 55%He-43%Ar-2%CO_2 shielding gas;
- 1.5 m/min welding speed;
- MAG arc trailing the laser;
- 0mm separation between the MAG arc and the CO_2 laser in the molten pool.